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TIME RESPONSE AND AERODYNAMIC HEATING OF ATMOSPHERIC TEMPERATURE SENSING ELEMENTS

by

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and
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UNITED STATES ARMY ELECTRONICS COMMAND

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ABSTRACT

Atmospheric temperature sensing elements described in this report are presently being used at Meteorological Rocket Network stations. The thermal time response and dissipation factors of the sensing elements and of their respective mounts are evaluated as functions of altitude. Aerodynamic corrections, which are a function of fall velocity of the sensing instrument, are also presented. Utilizing empirical data, temperature-versus-altitude profiles obtained with the STS and Arcasonde systems are compared. The computer program in Fortran IV language, used to evaluate the above stated parameters, is summarized.

CONTENTS

INTRODUCTION

The thermal time response of atmospheric temperature sensing elements varies with respect to altitude and is dependent not only upon the heat transfer characteristics of the temperature sensing element but also upon the heat transfer characteristics of the sensor mount. Three distinct mounting configurations for temperature sensing elements described herein are currently being employed to measure atmospheric temperature at Meteorological Rocket Network (MRN) stations. The spherical bead thermistor serves as the temperature sensing element on the Arcasonde and Stratospheric Temperature Sonde (STS) rocketsondes, while the cylindrical rod thermistor is utilized on radiosondes.

The rocket-borne instruments are lifted to approximately 70 km, where the nose cone containing the payload is separated from the rocket. Immediately after separation, the nose cone is jettisoned, allowing the instrument to descend on an attached radar-reflective parachute. The parachute and instrument free fall a few kilometers until the parachute fully deploys at approximately 65 km. The sensing element and its telemetry instrument descend at a continuously decreasing velocity and transmit temperature-related data to a GMD receiver and TMQ-5 meteorological ground recorder.

The AN/AMT-4 radiosondes are suspended on helium- or hydrogen-filled balloons and ascend to approximately 40 km where the balloon bursts. Temperature-related data are transmitted from the radiosonde to the meteorological receiver and recorder.

Determination of the velocity of the temperature sensor relative to the surrounding air, calculations of the related aerodynamic heating of the air surrounding the sensor, and a knowledge of the dissipation factor and time constants of the temperature sensor permit calculation of corrections for aerodynamic heating.

THERMAL TIME RESPONSE OF THERMISTORS AND FILMS

From the solution of Newton's law of cooling equation, $\Delta T = \Delta T_o e^{-Ct}$, one time constant of the temperature sensing device is defined as $T = 1/C$. Expressions for the thermal time constants and dissipation

factors were derived by Ballard (1966) and are of the form:

$$T = 1/C = \frac{mc}{S} \tag{1}$$

$$S = h(Z)A + \frac{2k\beta}{X} + 4\sigma A T_e^3(Z)_e \tag{2}$$

where

S - total dissipation factor
m - mass
C_p - element specific heat
h - coefficient of convective heat transfer
A - surface area
σ - Stefan-Boltzmann constant
T_e - temperature of the environment
k - thermal conductivity
β - cross-sectional area
X - characteristic length
Z - altitude

The term $h(Z)A$ is the expression for the rate of thermal energy transfer due to convection. It can be observed from equation 2 that the coefficient of convective heat transfer is a function of altitude. This coefficient is also dependent on the surface shape of the considered object. Values for a small sphere are given by Barr (1961) and are plotted in Figure 1. The terms $2k\beta/X$ and $4\sigma AT_e^3$ denote the rate of thermal energy transfer due to conduction and radiation, respectively.

A. Spherical Thermistor: Time Constant and Dissipation Factor

Sensors currently in use on the Arcasonde and STS instrument are the 0.032 cm diameter aluminum-coated spherical thermistors with platinum-iridium lead wires 0.3 cm long. The lead wires are attached to the aluminum coating on the thin film mount to conduct heat away from the bead to a larger heat dissipation area, the film's surfaces. The aluminum also serves as an effective reflector of solar radiation. Mount configurations are shown in Figure 2 for the STS film and in Figure 3 for the Arcasonde film.

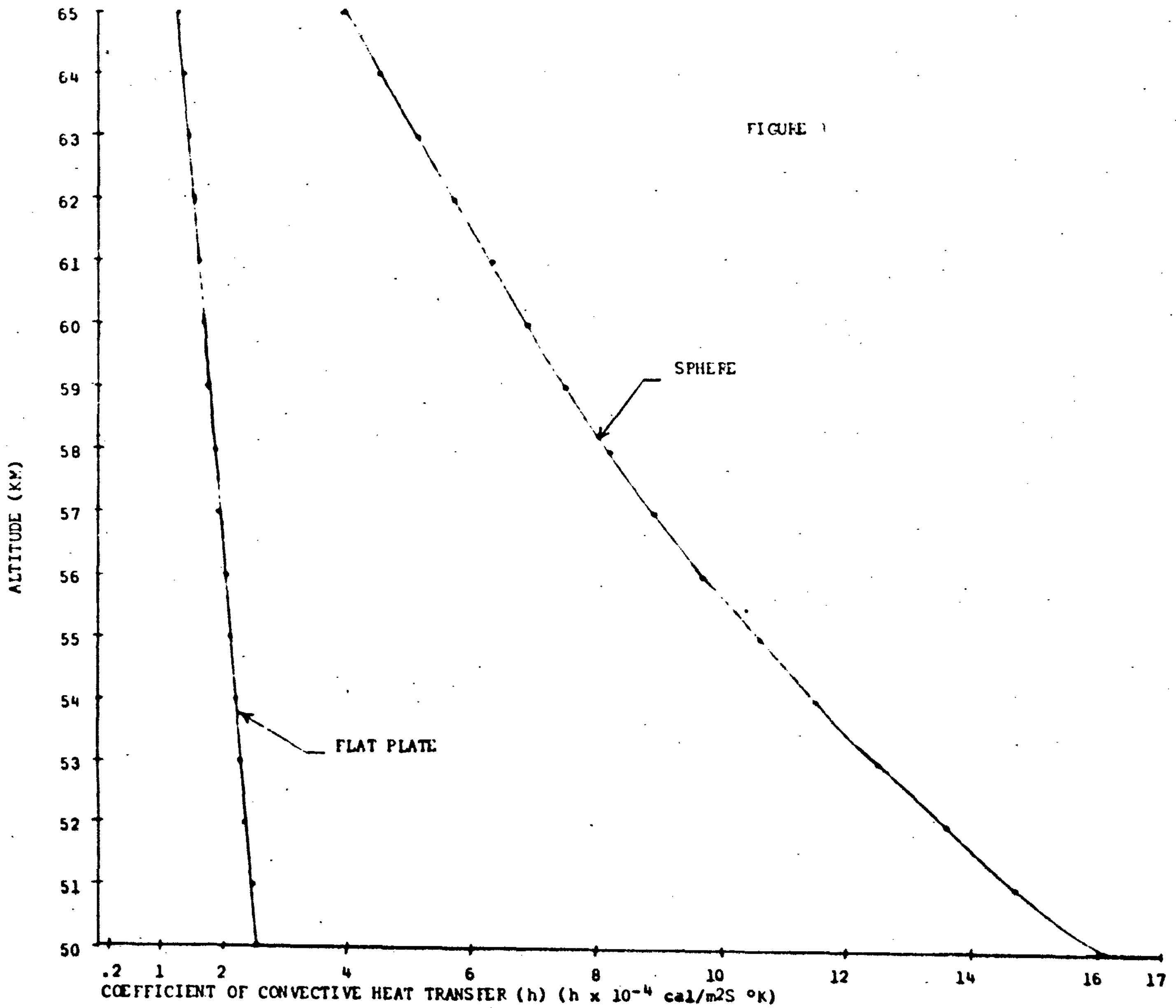
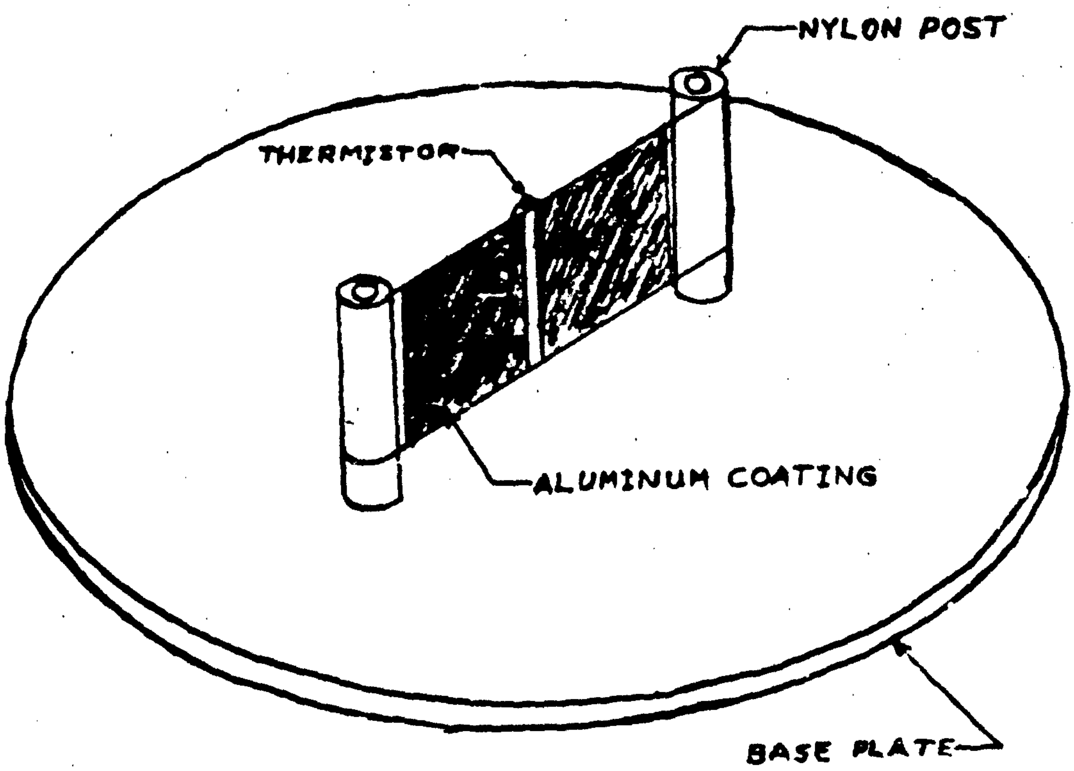


FIGURE
SPHERE
FLAT PLATE
ALTITUDE (KM)
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
.2
1
2
4
6
8
10
12
14
16
17
COEFFICIENT OF CONVECTIVE HEAT TRANSFER (h) (h x 10^{-4} cal/m2S °K)



STS Film and Thermistor Arrangement

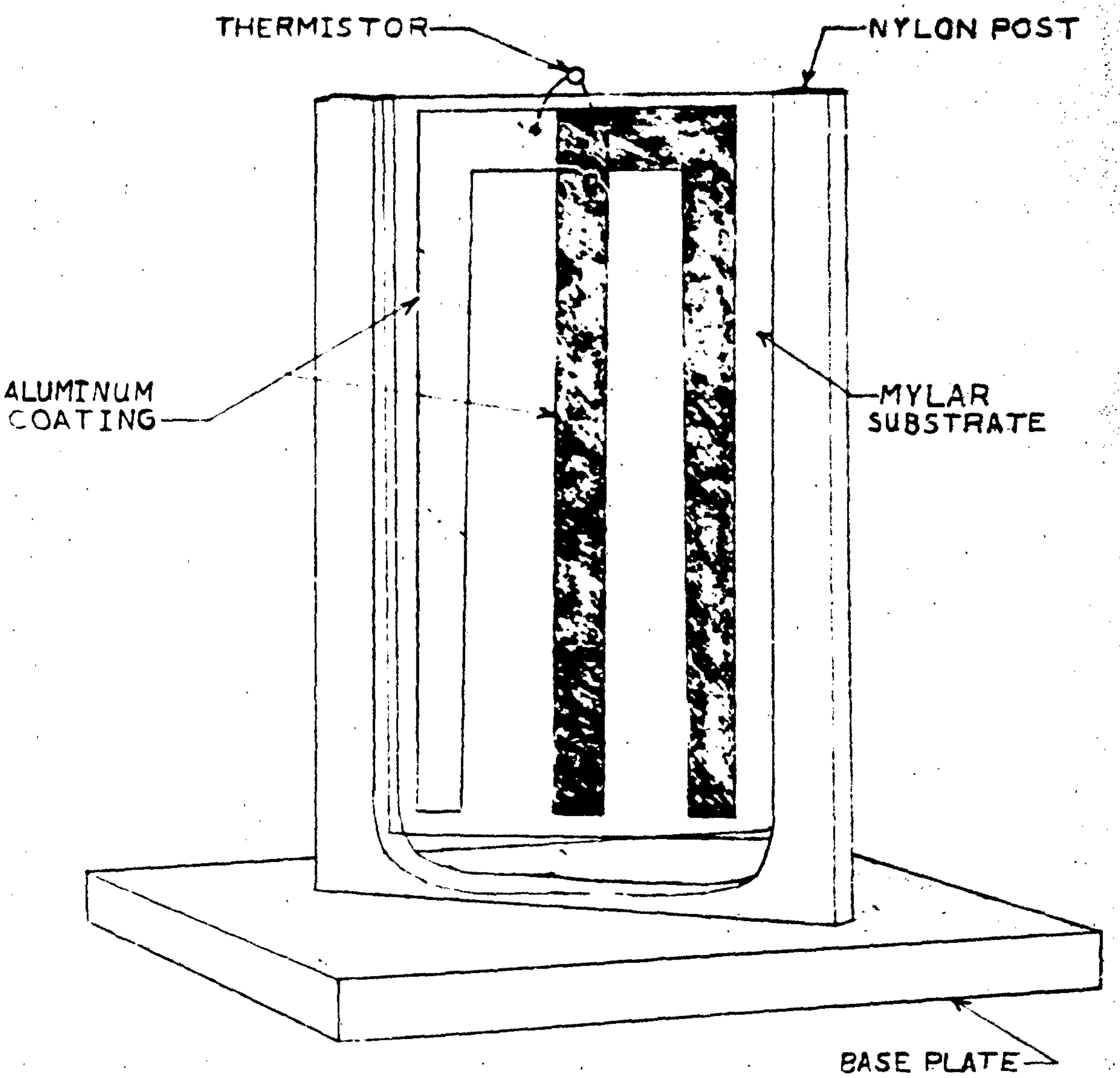
Thermistor Characteristics

m	thermistor mass	3.9×10^{-5} gm
c	specific heat of the thermistor	.18 cal/gm °K
A	thermistor surface area	3.22×10^{-3} cm^2
β	cross sectional area of lead wires	5×10^{-6} cm^2
k	thermal conductivity of lead wires	7.4×10^{-2} cal/3°K cm
X	lead wire length	.3 cm

Film Characteristics

m	film mass	4.5×10^{-3} gm
c	specific heat of mylar	.2 cal/gm °K
A	film area	6.4 cm^2
k	thermal conductivity of mylar	3.6×10^{-4} cal/S cm°K
β	cross sectional area of the film	1.3×10^{-3} cm^2
X	half width of the film	1.3 cm

FIGURE 2



Arcasonde Mylar film mount and bead thermistor. Bead characteristics are the same as those in the STS instrument.

Film Characteristics

A - film total surface area	10.16 cm^2
A - film coated surface area	3.42 cm^2
m - film total mass	4.13 X 10^{-2} gm
m - film coated mass	1.8 X 10^{-2} gm
β - film cross sectional area	1.68 X 10^{-2} cm^2
X - half-width of the film	.89 cm

FIGURE 3

Assume momentarily that the film is maintained at a lower temperature than the thermistor while in flight; then heat is conducted to the film through the lead wires so that there exists all three dissipation processes: convection, conduction, and radiation. Selecting temperatures at each altitude from the 1962 U.S. Standard Atmosphere and employing equations (1) and (2), results of thermistor time responses were obtained and are indicated in tabular form below. The heat capacity, mc, of the bead was found to be 7.02 X 10^{-6} cal/°C.

TABLE I

BEAD THERMISTOR TIME RESPONSE VS ALTITUDE

ALTITUDE KM	TEMPERATURE °C	DISSIPATION FACTOR μW/°C	TIME CONSTANT SEC
65	-34	16.3	1.83
64	-30	17.2	1.78
63	-26	18.0	1.70
62	-22	18.9	1.58
61	-20	19.7	1.52
60	-18	20.4	1.44
59	-16	21.4	1.37
58	-14	22.6	1.30
57	-12	23.4	1.25
56	-10	24.8	1.18
55	- 8	25.8	1.14
54	- 6	27.2	1.08
53	- 4	28.4	1.03
52	- 2	29.6	.99
51	- 2	31.4	.94
50	- 2	32.9	.89

B. Stratospheric Temperature Sonde Film Mount

The faces of the STS mylar film mount (Figure 2) are coated with very thin layers of aluminum, which distribute the heat energy over the surface area. Mylar is basically a nonconducting material. Narrow strips of aluminum are removed at the center and edges of the

film surfaces to prevent short circuiting the thermistor at the center and to avoid contamination of the temperature data with heat energy conducted from the support posts at the edges.

The film is oriented in flight with its surface area roughly parallel to the air flow direction. Values for coefficients of convective heat transfer for a flat plate exposed to fluid flow parallel to the surface are given by Ramsdale (1965) and plotted in Figure 1. The heat capacity of the STS film is 9.0×10^{-4} cal/^{o}C. Values of time response and dissipation factor of the STS film are given below in Table 2.

TABLE 2

STS FILM TIME RESPONSE VS ALTITUDE

ALTITUDE KM	TEMPERATURE ^{o}C	DISSIPATION FACTOR μW/^{o}C	TIME CONSTANT SEC
65	-34	5408.9	0.69
64	-30	5724.1	0.65
63	-26	6042.6	0.62
62	-22	6364.6	0.59
61	-20	6634.0	0.56
60	-18	6877.4	0.54
59	-16	7175.3	0.52
58	-14	7474.0	0.50
57	-12	7773.6	0.48
56	-10	8074.2	0.46
55	- 8	8348.9	0.45
54	- 6	8651.3	0.43
53	- 4	8954.6	0.42
52	- 2	9258.9	0.40
51	- 2	9499.6	0.39
50	- 2	9767.2	0.38

From Tables 1 and 2 it is noted that the film time constants are less than those of the thermistor at each altitude. As the thermistor and film ascend after launch, they are raised to the temperature that exists within the nose cone. This temperature reaches approximately

$370^{o}K$ due to aerodynamic heating of the nose cone. Immediately after ejection occurs, the thermistor and film are immersed in an atmosphere whose temperature is approximately $220^{o}K$. The film's faster response will allow it to reach the atmospheric temperature in advance of the bead thermistor. The temperature differential will cause heat energy to be conducted to the film. The term $2k\beta/X$ in the expression for the film's dissipation factor pertains to the conductive dissipation through the film to the support posts.

C. Arcasonde Film Mount

A spherical bead thermistor and film mount are arranged in much the same manner as on the STS instrument. The thermistors have the same physical characteristics in both cases. Differences are in the film dimensions and aluminum coating. The Arcasonde mylar film has a larger surface area and is four times thicker than the STS film. The aluminum coatings are bifurcated strips on each side of the film mount (See Figure 3).

The analysis of the Arcasonde thermistor is the same as has been performed for the STS instrument. In investigating the Arcasonde film mount, it is useful to consider two possibilities. First, because of the low conductivity of mylar, the film area that dissipates the heat energy deposited by conduction from the thermistor is only that area coated with aluminum. The heat capacity of the mass which is behind the aluminum strips is 3.6×10^{-3} cal/^{o}C. Time responses of the Arcasonde film for this case are presented in Table 3.

TABLE 3

ARCASONDE FILM TIME RESPONSE VS ALTITUDE: COATED MASS

ALTITUDE KM	TEMPERATURE ^{o}C	DISSIPATION FACTOR μW/^{o}C	TIME CONSTANT SEC
65	-34	2945.6	5.28
64	-30	3114.0	5.00
63	-26	3284.2	4.74
62	-22	3456.3	4.50
61	-20	3600.2	4.32
60	-18	3730.3	4.17
59	-16	3889.5	4.00
58	-14	4049.1	3.84
57	-12	4209.2	3.70
56	-10	4369.9	3.56
55	- 8	4516.7	3.45
54	- 6	4678.2	3.33
53	- 4	4840.3	3.22
52	- 2	5002.9	3.11
51	- 2	5131.6	3.03
50	- 2	5274.5	2.95

Although mylar's thermal conductivity is low, there is some conduction to the uncoated film regions; therefore, the case in which the total volume aids in thermal dissipation was considered. The total mass has a heat capacity of 8.26×10^{-3} cal/^{o}C. Table 4 gives the resulting time response and dissipation factors.

TABLE 4

ARCASONDE FILM TIME RESPONSE VS ALTITUDE: TOTAL MASS

ALTITUDE KM	TEMPERATURE ^{o}C	DISSIPATION FACTOR μW/^{o}C	TIME CONSTANT SEC
65	-34	8638.6	3.99
64	-30	9139.0	3.77
63	-26	9644.7	3.58
62	-22	10155.9	3.40
61	-20	105[illegible]3.5	3.26
60	-18	10969.9	3.14
59	-16	11442.8	3.01
58	-14	11917.0	2.89
57	-12	12392.7	2.78
56	-10	12869.8	2.68
55	- 8	13305.9	2.59
54	- 6	13786.0	2.50
53	- 4	14267.5	2.42
52	- 2	14750.5	2.34
51	- 2	15132.7	2.28
50	- 2	15557.4	2.22

While neither of these conditions can be declared precisely correct, the limiting values of time constant and dissipation factor for altitudes between 65 and 50 km have been established to lie within 5.28 seconds and 2.22 seconds with corresponding dissipation factors of 2945 μW/^{o}C and 15557.4 μW/^{o}C, respectively.

D. Radiosonde Cylindrical Thermistor

To establish thermal time response and dissipation factor of the radiosonde thermistor, a brief analysis was performed on the Bendix-Friez cylindrical thermistor (model number 51322-1) which is used

on the ML-419/AMT-4 radiosonde instrument currently flown at White Sands Missile Range. The thermistor unit is a thin ceramic rod provided with tinned copper leads at both ends and coated with a waterproof white material that is an effective reflector of solar radiation. This reflective coating is not applied uniformly or in equal quantities, and, therefore, the mass and total surface area vary from one device to another. An average mass of .12 gm and an average surface area of 1.5 cm^2 were determined from eight different thermistors. The rod thermistor and its properties are shown in Figure 4. Specific heat was obtained empirically (0.14 cal/gm°C); the experiment was performed by Schellenger Research Laboratories, University of Texas at El Paso.

To find the coefficient of convective heat transfer, the following equation was employed:

$$h = Nu \frac{K}{D} \tag{3}$$

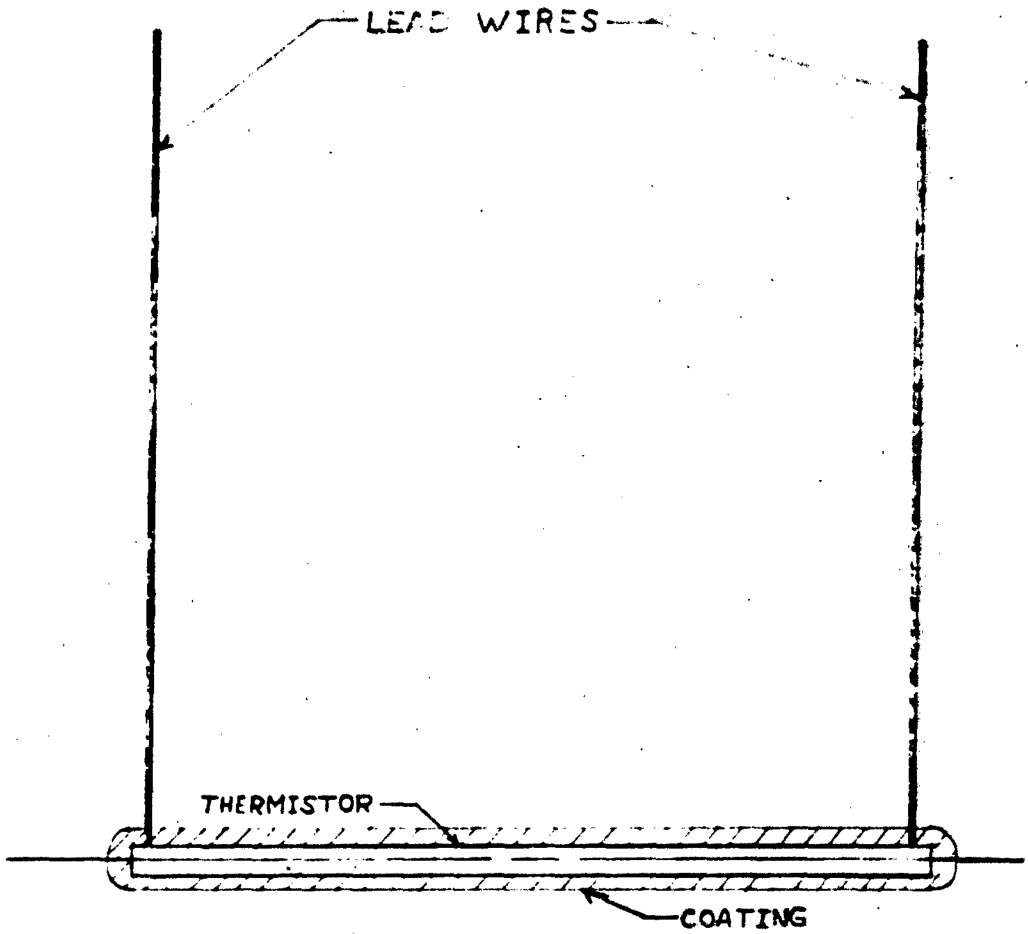
where Nu - Nusselt number
K - thermal conductivity of air
D - rod diameter

The Nusselt number was deduced from an empirically determined Nusselt equation (Eckert, 1963) for air flow perpendicular to the axis of the cylinder. Values tabulated for h are plotted in Figure 5. Time response calculations for the region from sea level to 40 kilometers yielded the following results:

TABLE 5

ROD THERMISTOR TIME RESPONSE VS ALTITUDE

ALTITUDE KM	TEMPERATURE °C	DISSIPATION FACTOR μW/°C	TIME CONSTANT SEC
40	-22	4213.9	16.3
35	-36	4743.2	14.5
30	-46	5854.5	11.7
25	-52	8582.6	8.0
20	-56	9252.7	7.4
15	-56	12638.5	5.4
10	-50	17684.1	3.9
5	-18	24391.8	2.8
0	18	33318.6	2.1

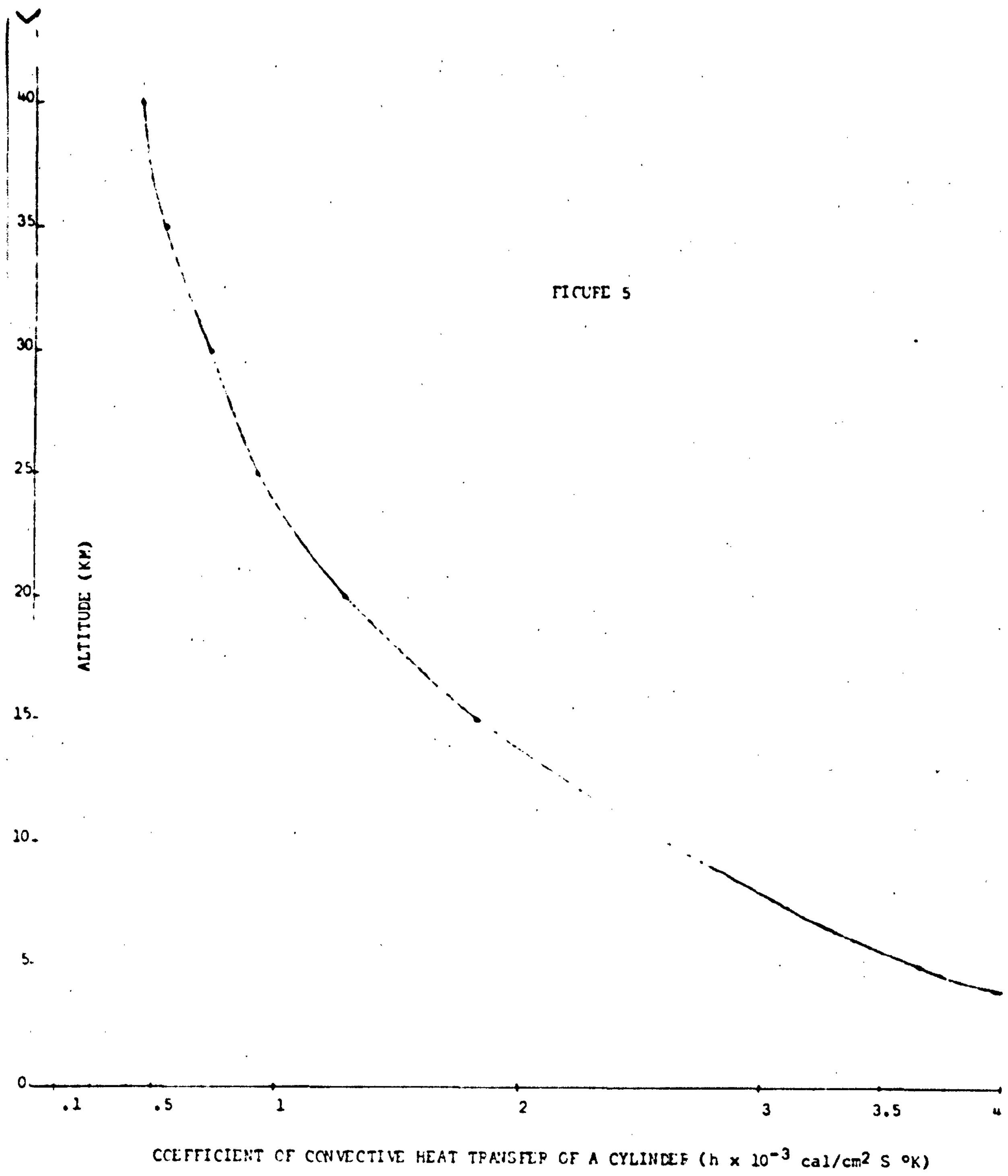


RADIOSONDE CYLINDRICAL THERMISTOR

Rod Characteristics

m - rod average mass	.12 gm
A - rod average surface area	1.5 cm^2
c - specific heat	.137 cal/gm °K
k - thermal conductivity of lead wires	.92 cal/cm S °K
β - cross-sectional area of lead wires	4.9 X 10^{-4} cm^2
X - lead-wire length	4 cm

FIGURE 4



FICUFE 5
ALTITUDE (KM)
40
35
30
25
20
15
10
5
0
.1
.5
1
2
3
3.5
4
COEFFICIENT OF CONVECTIVE HEAT TRANSFER OF A CYLINDER (h x 10^{-3} cal/cm² S °K)

EFFECTS OF AERODYNAMIC HEATING

After expulsion, the rocketsonde temperature sensing system descends such that the thermistor is the first element of the system to enter any particular region of the atmosphere. Viewing the arrangement from top to bottom, there is the parachute, the telemetry package suspended on the parachute shroudlines, the film mount on the lower end of the telemetry package, and finally the thermistor at the lower edge of the film. Viscous stresses within the boundary layer adjacent to the bead and film exert a shearing force on the fluid and raise its temperature. An expression for the temperature change of the fluid layer which surrounds the bead and film has the form $\Delta T_A = rv^2/2C_p$, where r is the recovery factor, v is the velocity, and C_p is the specific heat of air at constant pressure.

A. Bead Thermistor

The STS and Arcasonde instruments, at 65 kilometers, occasionally possess a component of horizontal velocity which was imparted to them by the missile; however, only the vertical velocity component was used to calculate aerodynamic heating at this altitude. At 64 kilometers and thereafter, the parachute is fully wind sensitive so that the increase in thermal energy is based on vertical fall velocity only. For a spherical body, the recovery factor, in the slip flow to continuous flow regime is given by the empirical expressions derived by Wagner (1964) which are of the form

$$r = \begin{cases} 0.0173z - 0.024 & 80.0 > z > 53.4 \\ 0.90 & 53.4 > z > 30.0 \end{cases}$$

where z is the altitude in kilometers.

Calculations for the aerodynamic heating in the region from 65 to 50 kilometers yielded the results given in Table 6.

TABLE 6

AERODYNAMIC HEATING OF AIR ADJACENT TO THE BEAD THERMISTOR

ALTITUDE KM	VELOCITY MPS	RECOVERY FACTOR	AERODYNAMIC HEATING °C
65	167	1.10	15.4
64	159	1.08	13.7
63	150	1.07	12.0
62	142	1.05	10.6
61	133	1.03	9.1
60	125	1.01	7.9
59	117	0.99	6.8
58	110	0.98	5.9
57	103	0.96	5.1
56	96	0.94	4.4
55	90	0.93	3.8
54	83	0.91	3.1
53	78	0.90	2.7
52	73	0.90	2.4
51	66	0.90	2.0
50	61	0.90	1.7

Velocities utilized are those from the standard fall rate (Ballard, 1967).

B. Film Mounts

The mylar film between the nylon support posts behaves as a flat plate with air flow parallel to its surface. For laminar flow and forced convection, the recovery factor of a flat plate (Kreith, 1961) was found to be:

$$r = \sqrt{u\, C_p / K} \tag{5}$$

u - fluid viscosity
C_p - specific heat at constant pressure of the fluid
K - thermal conductivity of the fluid.

Insertion of appropriate values, from the U. S. 1962 Standard Atmosphere, into equation 5 for the region from 65 to 50 kilometers yielded recovery factors of .85 to .844. A change of .006 for recovery factor from 65 to 50 kilometers was considered negligible, and thus a constant recovery factor of .85 was used in all computations for the film mounts. The results of these computations are summarized in Table 7.

TABLE 7

AERODYNAMIC HEATING OF AIR ADJACENT TO THE FILM MOUNTS

ALTITUDE KM	VELOCITY MPS	AERODYNAMIC HEATING °C
65	167	11.9
64	159	10.7
63	150	9.6
62	142	8.6
61	133	7.5
60	125	6.6
59	117	5.8
58	110	5.1
57	103	4.5
56	96	3.9
55	90	3.4
54	83	2.9
53	78	2.6
52	73	2.3
51	66	1.9
50	61	1.6

C. Rod Thermistor

The effects of aerodynamic heating of the cylindrical thermistor were considered. Radiosonde balloons rise at a slow and fairly constant velocity of 5 meters per second, which gives a temperature increase too small to be taken into account. A sample calculation will demonstrate this. Assuming a recovery factor of one:

$$\Delta T = r \frac{v^2}{2\,C_p} = 1 \cdot \frac{(5\text{m/s})^2}{2 \times 10^3\ \text{m}^2/\text{s}^2\ {}^\circ\text{C}} = .0125^\circ\text{C}$$

CORRECTIONS FOR AERODYNAMIC HEATING

Aerodynamic heating establishes a temperature differential between the spherical bead or film wall and the fluid boundary layer adjacent to the surfaces. Fluid friction has caused a heating action to occur which raised the temperature of the fluid above that of the thermistor bead. The bead is thus subsequently heated, and it becomes necessary to find a correction factor for the amount of transferred thermal energy. An expression for change in temperature of the bead or film due to aerodynamic heating may be found by considering that the amount of thermal energy transferred from the fluid boundary layer to the thermistor is known to be, $h(Z)A\Delta T_A$. Out of this convected heat energy, an amount S ($\mu W/^{o}C$) is dissipated, leaving an increase in temperature of

$$\Delta T = \frac{h(Z)A\ \Delta T_A}{S}$$

or

$$\Delta T = \left(\frac{h(Z)A}{h(Z)A + \frac{2k\beta}{X} + 4\sigma A T_e^3}\right) \cdot \left(r \frac{v^2}{2C_p}\right) \qquad (6)$$

Utilizing equation (6), correction temperatures were calculated for the STS and Arcasonde film and for the thermistor bead. Correction values for the Arcasonde are those corresponding to the dissipation factor where the total film volume was considered to be dissipating heat energy. These correction values are given in Table 8.

TABLE 8

TEMPERATURE CORRECTION

ALTITUDE KM	BEAD °C	ARCASONDE FILM °C	STS FILM °C
65	-4.9	-7.5	-7.5
64	-4.8	-6.8	-6.8
63	-4.5	-6.1	-6.1
62	-4.3	-5.5	-5.5
61	-3.9	-4.8	-4.9
60	-3.5	-4.3	-4.3
59	-3.2	-3.8	-3.8
58	-3.0	-3.4	-3.4
57	-2.6	-3.0	-3.0
56	-2.4	-2.6	-2.6
55	-2.1	-2.3	-2.3
54	-1.8	-2.0	-2.0
53	-1.6	-1.8	-1.8
52	-1.5	-1.6	-1.6
51	-1.2	-1.3	-1.3
50	-1.1	-1.1	-1.1

It is immediately noticed that once aerodynamic heating effects are felt by the system, the film becomes warmer than the bead. At 64 kilometers when the parachute is fully wind sensitive, the difference in temperature due to aerodynamic heating for the bead and STS film is 2°C. The lead wires from the film to the bead conduct at 10.1 μW/°C; therefore, the thermistor receives 20.2 microwatts of thermal energy. The bead's dissipation rate is 17.2 μW/°C at 64 kilometers. Thus, the increase in temperature of the thermistor is 1.2°C, and an additional correction must be introduced to the previous ones to account for conductive heating of the thermistor by its film mount. At lower altitudes the temperature difference becomes less (as observed in the tables). It does not exceed 2°C after the parachute is fully deployed. This differential diminishes to zero at approximately 50 kilometers. The final corrections are tabulated below:

TABLE 9

ALTITUDE KM	STS Corrections ADDED °C	STS Corrections FINAL °C	Arcasonde Corrections ADDED °C	Arcasonde Corrections FINAL °C
65	-1.6	-6.5	-1.6	-6.5
64	-1.2	-6.0	-1.2	-6.0
63	-0.9	-5.4	-0.9	-5.4
62	-0.7	-4.9	-0.6	-5.0
61	-0.5	-4.4	-0.5	-4.3
60	-0.4	-3.9	-0.4	-3.8
59	-0.3	-3.5	-0.3	-3.5
58	-0.2	-3.2	-0.2	-3.1
57	-0.2	-2.8	-0.2	-2.8
56	-0.1	-2.5	-0.1	-2.5
55	-0.1	-2.2	-0.1	-2.2
54	-0.1	-1.9	-0.1	-1.9
53	-0.1	-1.7	-0.1	-1.7
52	----	-1.5	----	-1.5
51	----	-1.3	----	-1.3
50	----	-1.1	----	-1.1

TEMPERATURE-ALTITUDE COMPARISONS (ARCASONDE AND STS)

Temperature-altitude profiles obtained on 8 June 1966 are shown in Figure 6. An Arcasonde was launched at 1155 MST while an STS instrument was launched at 1308 MST. The profiles in Figure 6 are not corrected for aerodynamic heating. Expulsion of the Arcasonde occurred near 82 kilometers and the instrument proceeded to free fall after expulsion since the air density was too low at these altitudes for parachute deployment. Here the effects of aerodynamic heating are clearly seen since the instrument measured temperatures as high as 70°C in the 68 kilometer region. The STS instrument was ejected at a lower altitude with parachute deployment following shortly thereafter such that aerodynamic heating was not as evident as in the Arcasonde flight. In Figure 7 the temperatures in the 65-50 kilometer region have been corrected to compensate for aerodynamic heating effects. Both instruments gave equivalent temperature-versus-altitude data. It is not intended that this technique be applied to data obtained before the parachute is fully deployed because these corrections are contingent on the film mount's orientation during descent.

FORTRAN IV COMPUTER PROGRAM

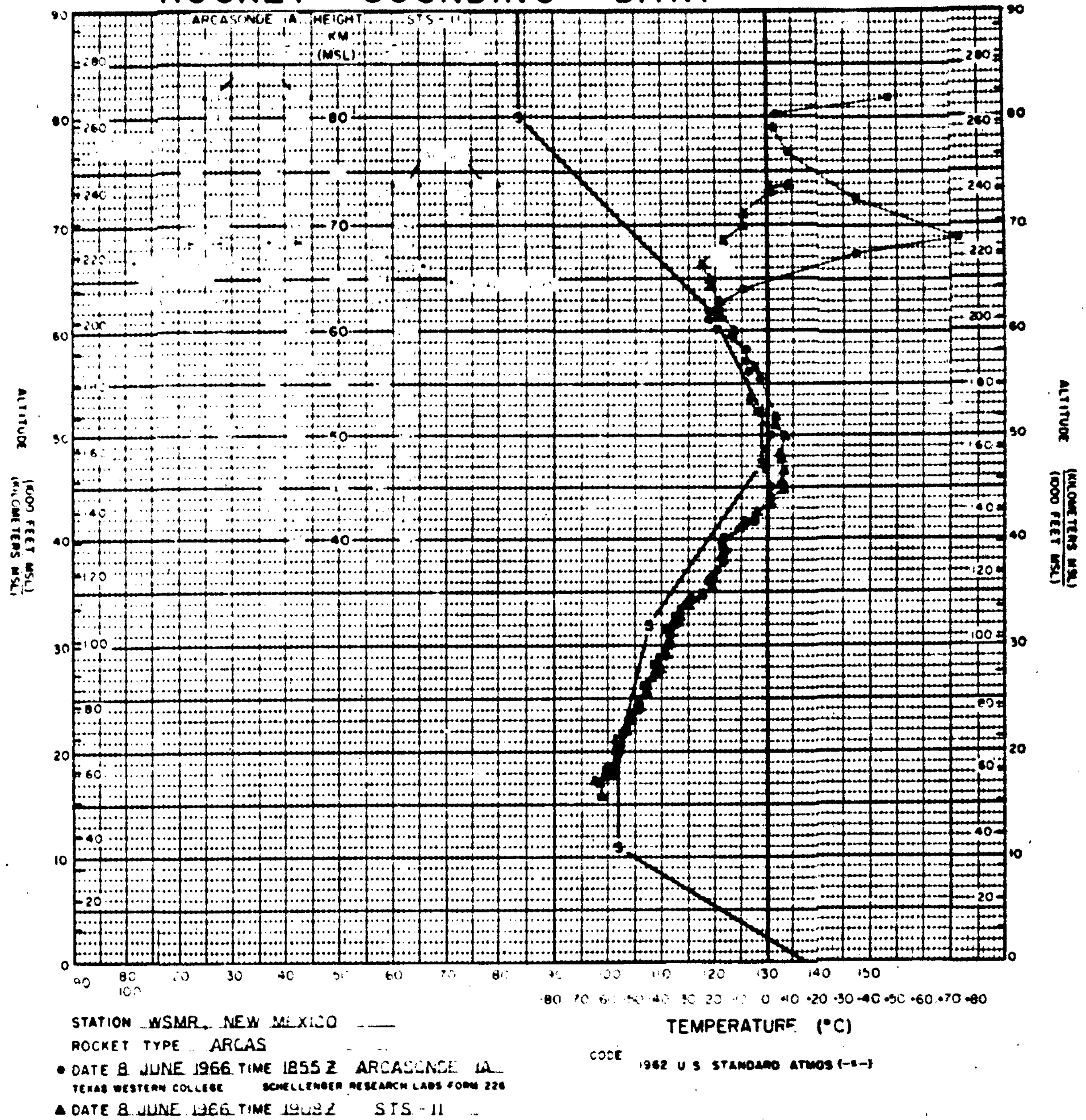
A Fortran IV language digital computer program was coded to evaluate all the tabulated data that have been listed. The block diagram in Figure 8 demonstrates the flow of general operations of the program. Processing required approximately three minutes on an IBM 7094 machine; this included compilation time. The program is versatile in that temperatures, velocities, coefficients of convective heating, number of points desired, and sensor measurements may be altered by modifying a few input cards. An actual program coding for the spherical thermistor corrections is shown in Figure 9.

CONCLUSIONS

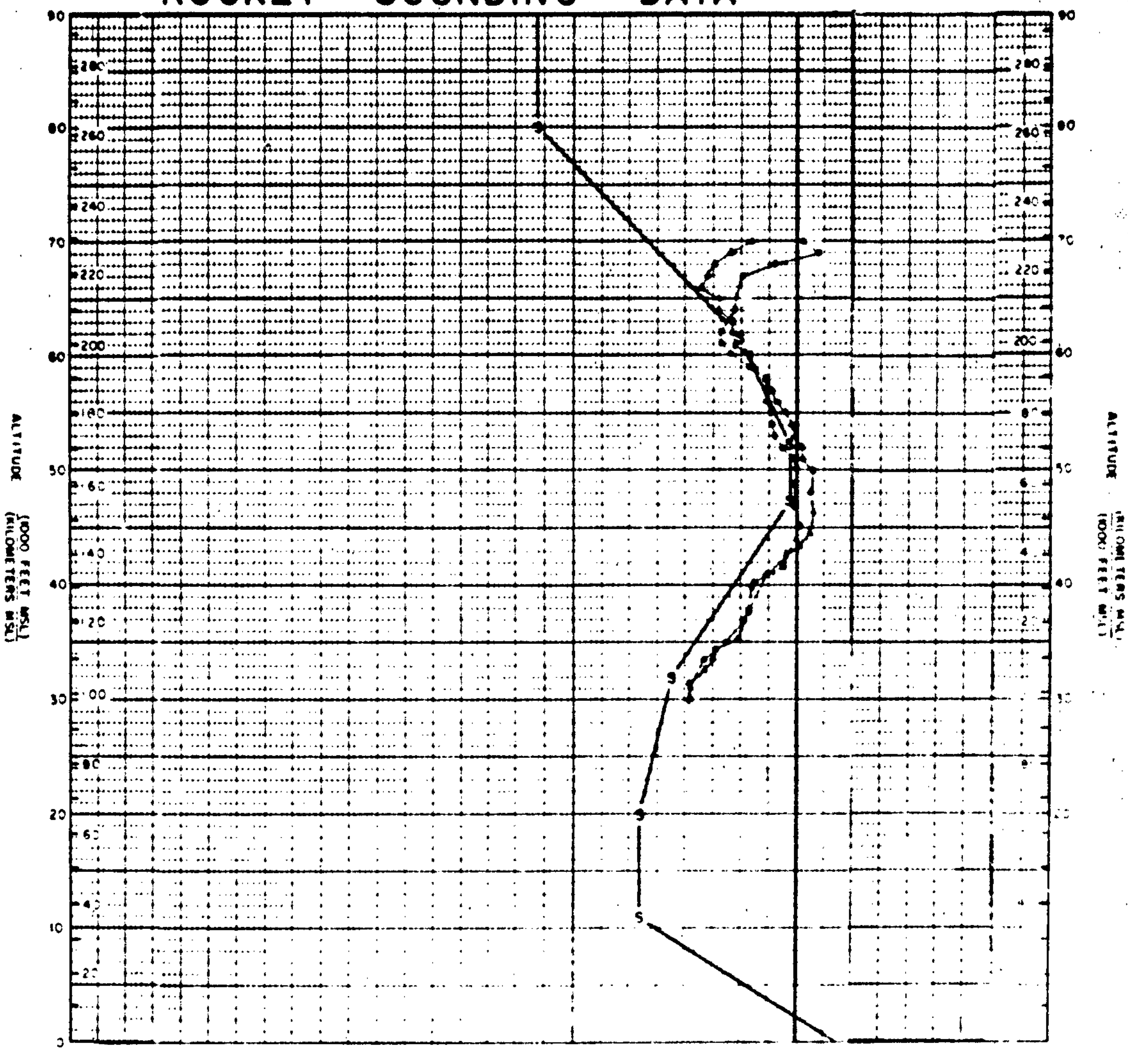
Experimental comparisons of temperature-altitude profiles obtained with the STS and Arcasonde instruments indicate that the response of the two instruments is essentially the same, in agreement with the findings of the theoretical study. The total temperature correction for both instruments is approximately 6.5°C at 65 km, decreasing to approximately 1°C at 50 km.

FIGURE 6

ROCKET SOUNDING DATA



ROCKET SOUNDING DATA



STATION WSMR, NEW MEXICO
ARCAS
• 8 JUNE 66 1855 Z ARCASONDE 1A
• DATE 8 JUNE 66 TIME 2008 Z STS-11

FIGURE 7

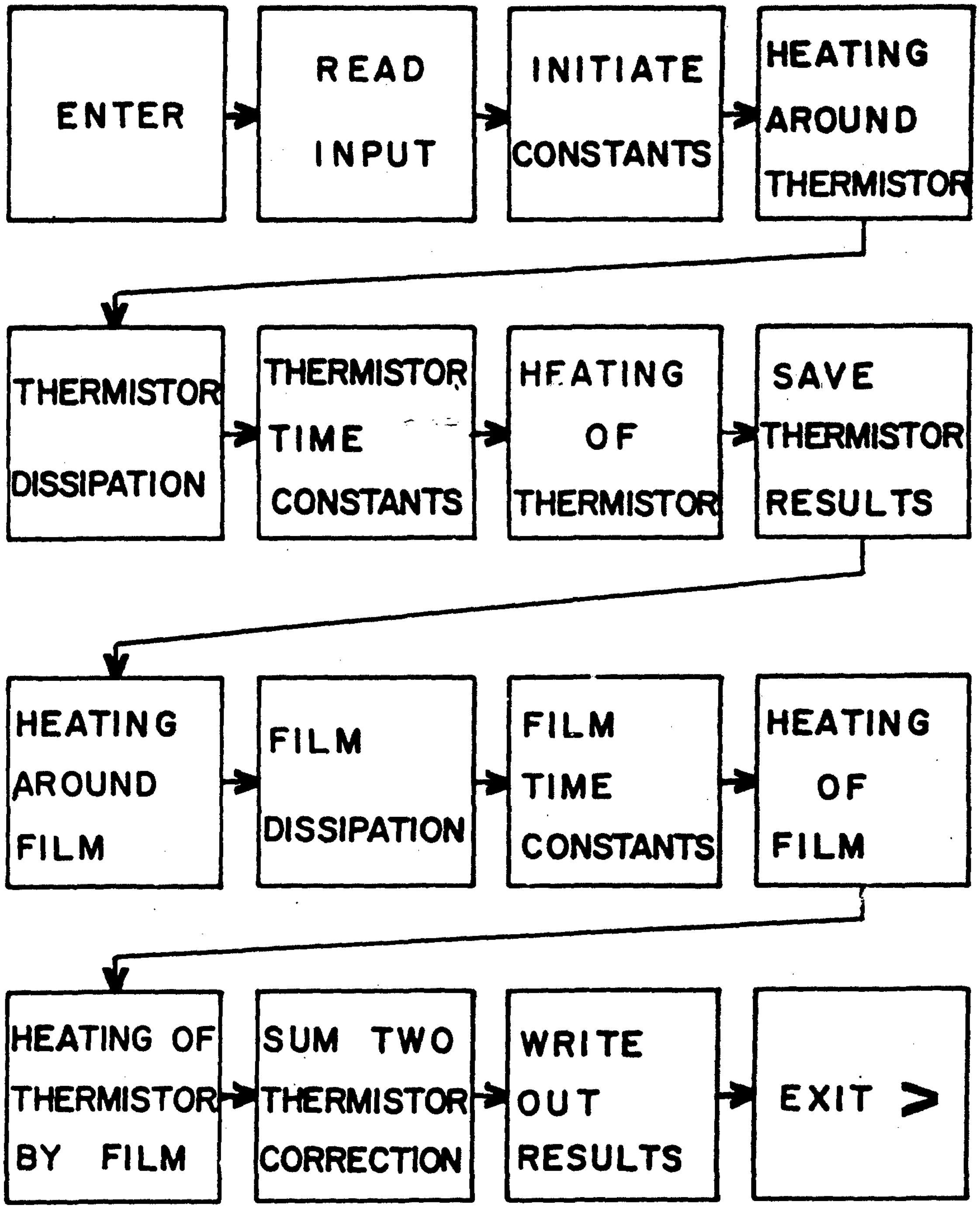


FIGURE 8
SUMMARY OF FORTRAN COMPUTER PROGRAM

```
      DIMENSION V(16),T(16),H(16),TAC(16),S(16),COR(16),TAU(16)
      DIMENSION  CV(16),CD(16),RD(16),CORB(16),FCOR(16),SB(16)
      REAL MASS
      READ(5,3) N
      READ(5,1) (V(I),I=1,N)
      READ(5,1) (T(I),I=1,N)
   16 READ(5,2) (H(I),I=1,N)
      READ(5,9) SPH,LEN,VOL,A,BETA,FK,MW,NF
    1 FORMAT (16F5.0)
    2 FORMAT (8E10.2)
    3 FORMAT (I5)
    4 FORMAT  (1H1,10X8HALTITUDE,10X16HFINAL CORRECTION)
    5 FORMAT (1H1,38X18HCORRECTION FACTORS/1H-, 2X8HVELOCITY,7X4HTEMP,10
     1X3HALT, 5X15HDYNAMIC HEATING,10X11HDISSAPATION,10X10HCORRECTION,6X
     213HTIME CONSTSNT/1H+, 4X3HM/S,13X1HC,13X2HKM,13X5HDEG K,20X4HUW/K,
     318X1HK,13X3HSEC)
    6 FORMAT(1H0,   F6.0,10XF5.0,11XF3.0,12XF6.2,14XF9.2,15XF6.2,9XF6.2)
    7 FORMAT (1H+,10XF8.2,12XF7.2,12XF8.2)
    8 FORMAT (1H1,10X10HCONVECTION,10X10HCONDUCTION,10X10HRADIATION )
    9 FORMAT (/F11.7,I3)
   14 FORMAT  (1H+,11XF3.0,16XF7.2)
      SIG=5.67E-12
      CP=1000.
      SPH=SPH*4.18
      MASS=LEN*VOL
      IF(NF.EQ.1) GO TO 11
   15 ALT=65.
      DO 10 I=1,N
      TAC(I)=(.9*V(I)**2)/(2.*CP)
      IF(ALT.LT.53.) TAC(I)=((.0173*ALT-.024)*V(I)**2)/(2.*CP)
   10 ALT=ALT-1.
      GO TO 13
   11 ALT=65
      DO 12 I=1,N
      TAC(I)=(.85*V(I)**2)/(2.*CP)
   12 ALT=ALT-1.
   13 DO 20 I=1,N
      CV(I)=A*H(I)*4.18*(10.**6)
      CD(I)=(2.*FK*BETA*4.18*(10.**6))/MW
      RD(I)=A*4.*SIG*((T(I)+273.)**3)*(10.**6)
      S(I)=CV(I)+RD(I)+CD(I)
      TAU(I)=MASS*SPH*(10.**6)/S(I)
   20 COR(I)=(A*H(I)*4.18*(10.**6)*TAC(I))/S(I)
      WRITE(6,5)
      ALT=65.
      DO 30 I=1,N
      WRITE(6,6)  V(I),T(I),ALT,TAC(I),S(I),COR(I),TAU(I)
   30 ALT=ALT-1.
      WRITE(6,8)
      WRITE(6,7)(CV(I),CD(I),RD(I),I=1,N)
      IF(NF.EQ.1) GO TO 40
      DO 22 I=1,N
      SB(I)=S(I)
   22 CORB(I)=COR(I)
      GO TO 16
   40 WRITE(6,4)
      ALT = 65.
      DO 24 I=1,N
      FC=(COR(I)-CORB(I))*10.1/SB(I)
      FCOR(I)=-(FC+CORB(I))
      WRITE (6,14) ALT,FCOR(I)
   24 ALT=ALT-1.
      STOP
      END
```


FIGURE 9

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13. ABSTRACT

Atmospheric temperature sensing elements described in this report are presently being used at Meteorological Rocket Network stations. The thermal time response and dissipation factors of the sensing elements and of their respective mounts are evaluated as functions of altitude. Aerodynamic corrections, which are a function of fall velocity of the sensing instrument, are also presented. Utilizing empirical data, temperature-versus-altitude profiles obtained with the STS and Arcasonde systems are compared. The computer program in Fortran IV language, used to evaluate the above stated parameters, is summarized.

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